Nonlocal Optical Response in CdTe Photovoltaics

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ABSTRACT

We study the nonlocal response to the laser beam in CdTe photovoltaics. The laser-generated plasma is shown to spatially decay over a considerable distance. This affects the surface photovoltage and open circuit voltage far from the laser spot. Associated with such nonlocal response are also features in PL mapping where different excitation powers lead to different map topologies. We have developed a theory that expresses the effects of laser-generated plasma spreading in terms of the semiconductor film photovoltaic parameters.

1. Introduction

It is assumed in most photoluminescence (PL) studies that the laser-beam-generated charged carriers do not propagate far into the surrounding area and thus PL is emitted directly from under the laser beam. PL mapping and micro-PL mapping [1] are well known implications of that assumption aimed at studying variations in local properties of a material. Optical beam induced current (OBIC) techniques proceed from the analogous premise [2]. However, in the OBIC setup the carriers are swept away from the device and do not accumulate, which makes it different from that of PL.

In general, the above assumption implies that the charge carrier drift and diffusion in the system are suppressed. To verify the above assumption we have conducted the following experiments. 1) Measurements of the surface photovoltage and the open circuit voltage of a cell depending on the distance between the cell (contact) edge and the laser beam spot outside the cell. This provides another way to characterize the spatial decay of the laser-generated plasma. 2) PL mapping with laser beams of different intensities (laser beam diameter ~ 0.5 mm). In the absence of the electron-hole plasma spreading, the PL response would be purely local, leading to maps where the relief has the same topology but different amplitudes for different intensities. On the contrary, because of the electron-hole plasma spreading, different excitation powers will lead to different map topologies. This was observed in our experiments.

We have developed a theory that expresses the effects of laser-generated plasma spreading in terms of the semiconductor film photovoltaic parameters. From fitting the theory and experiment we were able to estimate the CdTe lateral conductivity and the characteristic spatial scale over which the laser-generated plasma decays.

2. Experimental

We measured Voc of a $1cm^2$ dot cell versus a distance from the laser spot of a diameter of ~0.5mm. The laser wavelength was 752 nm. As is seen from Fig. 1, the cell open circuit voltage in Fig. 1 decays over a considerable distance of the order of 1cm from the laser beam spot. We attribute this effect to the lateral spreading of the laser-generated plasma.

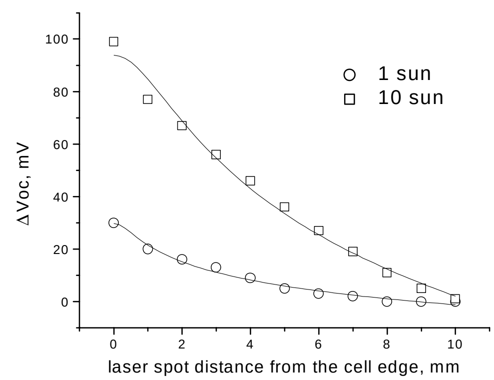


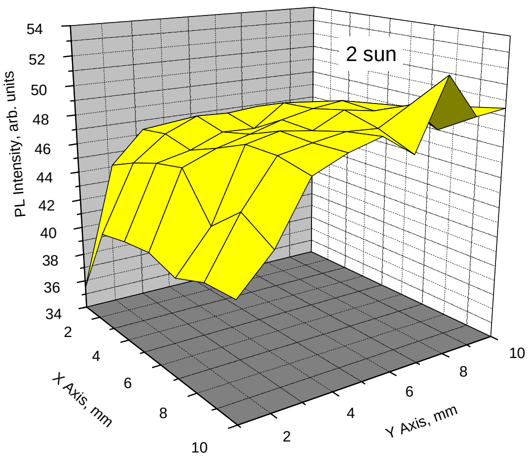
Fig 1. Change in the cell open circuit voltage versus the distance from the laser beam spot on the sample surface. Solid lines represent theoretical fit.

As the laser-generated plasma spreads over, it can emit light from the areas beyond the beam spot. This may be evidenced in the difference between the same area PL maps measured at different excitation powers, 2 suns and 20 suns (Fig. 2a, b).

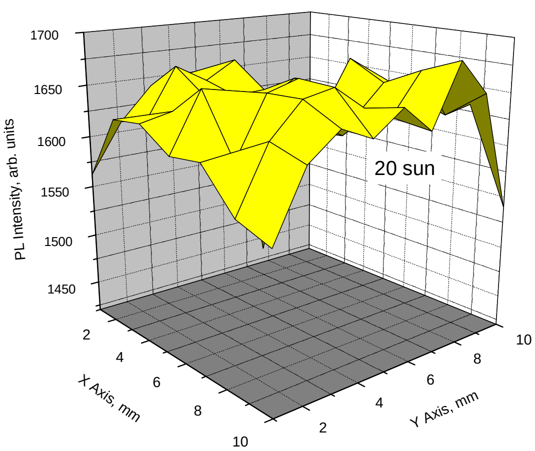
Note that the low intensity map shows the presence of the sample edge (y=0) at a distance of several millimeters, while it is not seen under the high intensity laser beam. We conclude that the plasma decay length decreases with the laser beam power.

3. Theory

We developed a theory of the laser beam generated plasma spreading in p-n junctions. The system was described as a set of microdiodes in parallel, where some local region corresponds to the area under the beam and is different from the rest of the system. The diode



(a)



(b)

Fig 2. PL maps of contact-free area corresponding to two different excitation powers.

interconnects are characterized by their specific resistances. In the case under consideration, one interconnect, the transparent conductive oxide (TCO) has a resistance that can be neglected as compared to that of the semiconductor film.

The photovoltaic I/V equation and the Ohm's law describe the electric potential φ distribution in the system,

$$\nabla \mathbf{J} = -j_0\left(\exp\left(\frac{\varphi}{T}\right)-1\right)+j_L, \quad \mathbf{J} = -\rho\nabla\varphi \tag{1}$$

Here J is the lateral current density, j_0 and j_L are the thermal and light-induced current densities in p-n junction, ρ is the sheet resistance of a (presumed) more conductive semiconductor layer forming p-n junction (CdTe in our case). The local open circuit voltages, corresponding to the dark (V_{oc}) and light (V_{oc}') regions are different,

$$V_{oc} = T\ln\left(\frac{j_L}{j_0}+1\right) \neq V_{oc}' = T\ln\left(\frac{j_L'}{j_0'}+1\right).$$

The difference results in a local forward bias, hence, an electric field that forces a lateral current. Because of the distributed resistance ρ, the electric potential and the current decay over some distance L that we call the screening length. The sheet resistance is voltage dependent,

$$\rho = \rho_0 \exp\left(-\frac{\alpha\varphi}{T}\right). \tag{2}$$

Here α (<1) is the fraction of the voltage drop across the presumed semiconductor layer under consideration.

Solving Eqs. (1) and (2) with proper boundary conditions give the electric potential distribution

$$\varphi = \varphi_0 - \frac{2T}{1-\alpha}\ln\left(1+\frac{x}{L}\right) \tag{3}$$

where the screening length,

$$L \approx L_0\left[\frac{J_L}{(j_0+j_L)L_0}\right]^{\frac{\alpha-1}{\alpha+1}}. \tag{4}$$

Here J_L is the laser generated current and L_0 is the screening length for the case of a small perturbation, φ-V_{oc}<<T,

$$L_0 = \left[\frac{T}{\alpha\rho_0(j_L+j_0)}\left(\frac{j_L+j_0}{j_0}\right)^{\alpha}\right]^{\frac{1}{2}}. \tag{5}$$

We have fit our data with Eq. (3) as is shown in Fig. 1. In addition, the following qualitative conclusions can be drawn: i) the screening length L decreases with increasing excitation current J_L; ii) L is independent of the ambient light; iii) the amplitude of the laser beam induced electric potential logarithmically increases with the excitation current and does not depend on the ambient light current; iv) the electric potential perturbation decays logarithmically with the distance from the laser beam. These conclusions are consistent with our data.

4. Conclusion

In conclusion, we have observed nonlocal response to the laser beam excitation in CdTe photovoltaics. Our model relates these observations to spreading of the electron-hole plasma beyond the laser beam spot.

5. Acknowledgments

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